National Taiwan University

中華民國科技部
Ministry of Science and Technology, R.O.C.

Underwater Acoustics Laboratory
水下聲學實驗室

Underwater noise impact assessment of the potential offshore wind farm sites in the west coast of Taiwan

Chi-Fang Chen[1,2],

Wei-Chieh Wang[1], Jeff Chih-Hao Wu[1], Wei-Chun Hu[1,2], Nai-Chang Chen[2], Yao-Sung Hsu[1], Dai-Hua Liu[1], Yin-Ying Fang[1], Wei-Shien Hwang[1]

[1]Department of Engineering Science and Ocean Engineering, NTU

[2]Ocean Technology Research Center, National Taiwan University

National Taiwan University

Underwater Acoustics Laboratory
水下聲學實驗室

OUTLINE

I. Introduction
II. Ambient Noise Measurement and Simulation
III. Pile Driving Noise Measurement and Analysis
IV. Noise Regulation
V. Noise Impact Simulation

National Taiwan University

Underwater Acoustics Laboratory
水下聲學實驗室

10 Year Global Wind Speed Rankings

http://www.4coffshore.com/windf

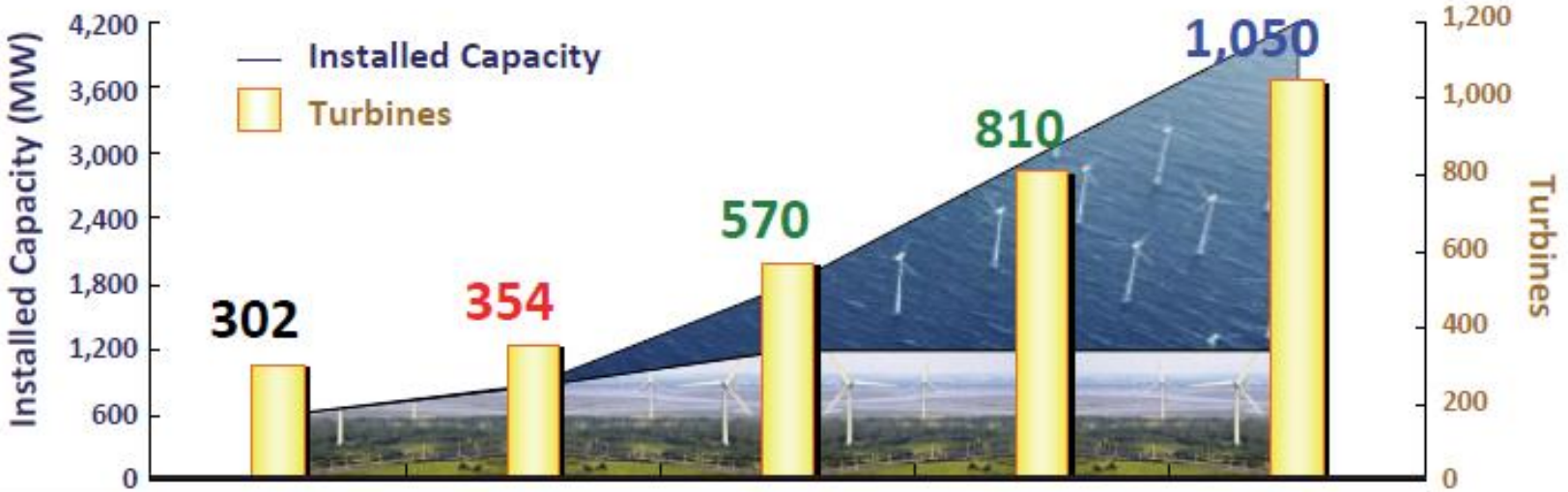
www.4coffshore.com/windfarms/windspeeds.aspx

Offshore Wind | Tidal | Transmission | Vessels | Ports | Equipment | News | Maps | Subscriptions | Downloads | Reports | Consult

5	Longyuan Putian Nanri Island 400MW project - Phase 2 - 196MW	Taiwan Strait	12.04
10	Zhanghua 1-1 - Development Zone	Taiwan Strait	12.03
10	Zhanghua 1-2 - Development Zone	Taiwan Strait	12.03
10	Zhanghua 1-5 - Development Zone	Taiwan Strait	12.03
10	Zhanghua 1-7 - Development Zone	Taiwan Strait	12.03
10	Zhanghua 3-3 - Development Zone	Taiwan Strait	12.03
10*	TECO/CSC 5MW Turbine (onshore)	Onshore	12.03*
16	Zhanghua 3-1 - Development Zone	Taiwan Strait	12.02

historic data...

Projected Wind Power Growth in Taiwan



Year	2012		2015		2020		2025		2030	
	MW	WTs	MW	WTs	MW	WTs	MW	WTs	MW	WTs
Onshore	596	302	866	350	1,200	450	1,200	450	1,200	450
Offshore	0	0	15	4	600	120	1,800	360	3,000	600
Total	596	302	881	354	1,800	570	3,000	810	4,200	1,050

工業技術研究院 Industrial Technology Research Institute

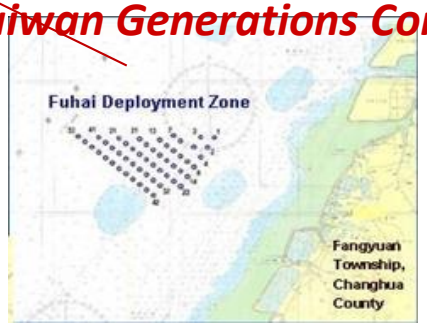
Ref. Bureau of Energy, Ministry of Economic Affairs, TAIWAN

© copyright 2012 ITRI

Taiwan's Offshore Wind Farm Pilot Projects

Miaoli-Chunan
Formosa Wind Power

Changhua-Fuhai
Taiwan Generations Corp

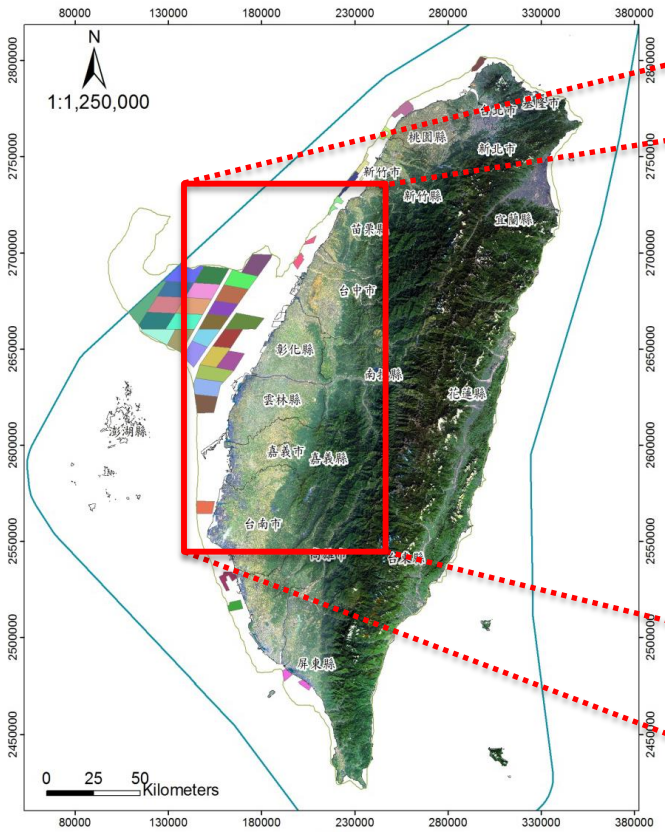


Yunlin-Star Energy
Taiwan Cogeneration Corp

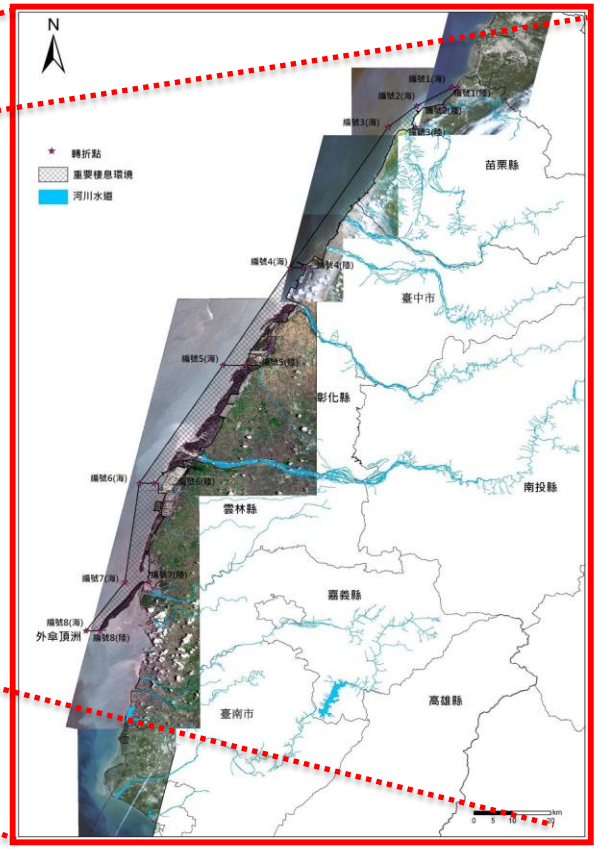
Chinese White Dolphin

(*Sousa chinensis* or Indo-Pacific Humpback Dolphin)

36 Potential Offshore Wind Farms

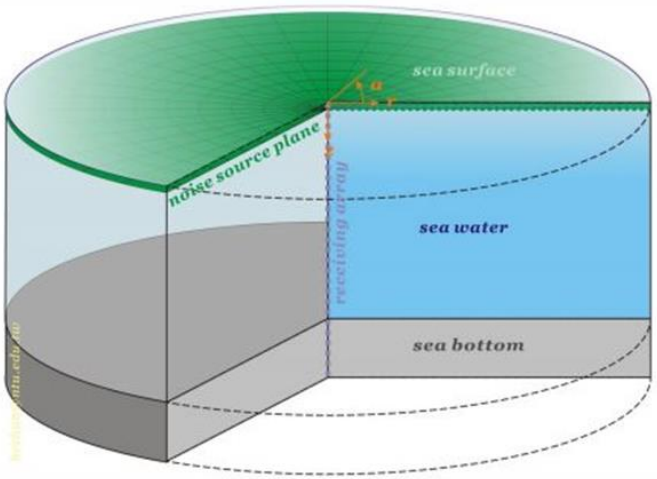


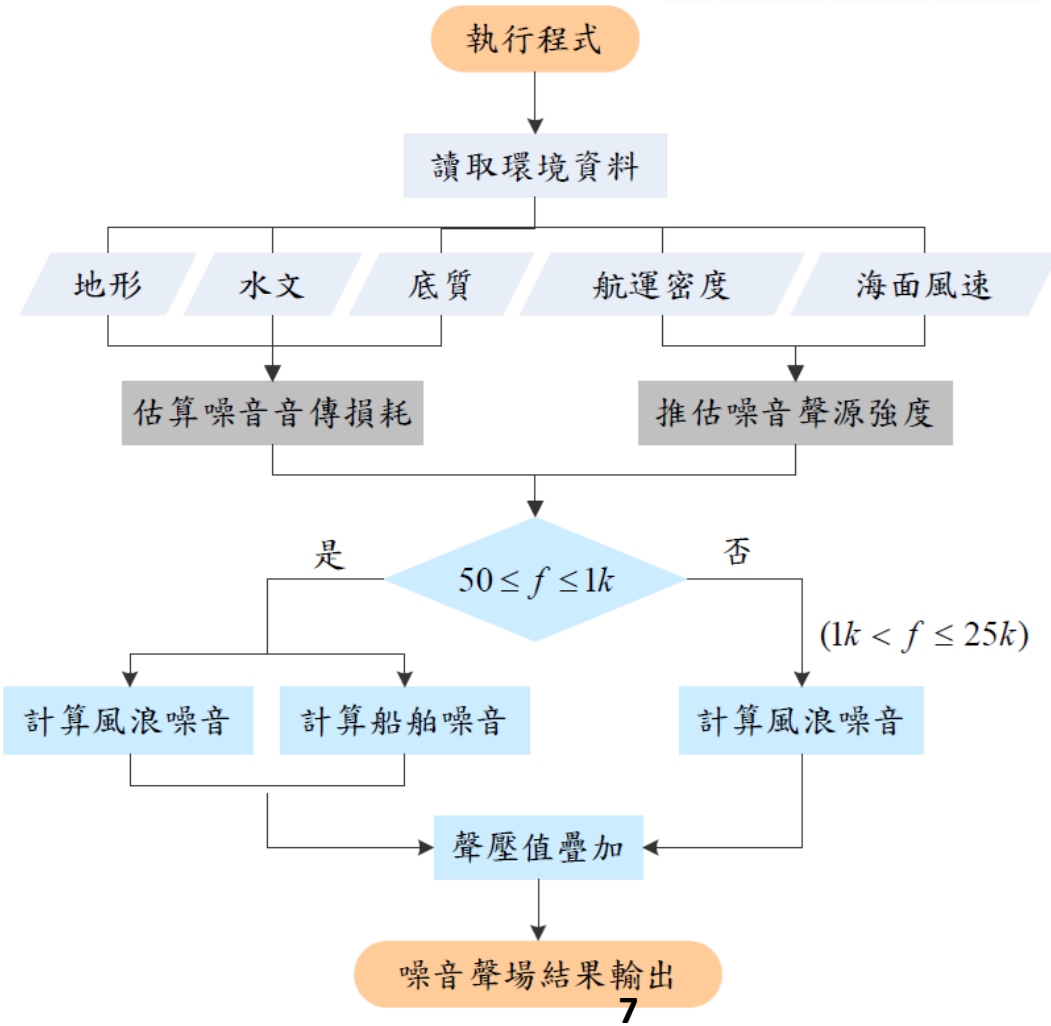
Habitats of the Chinese White Dophin



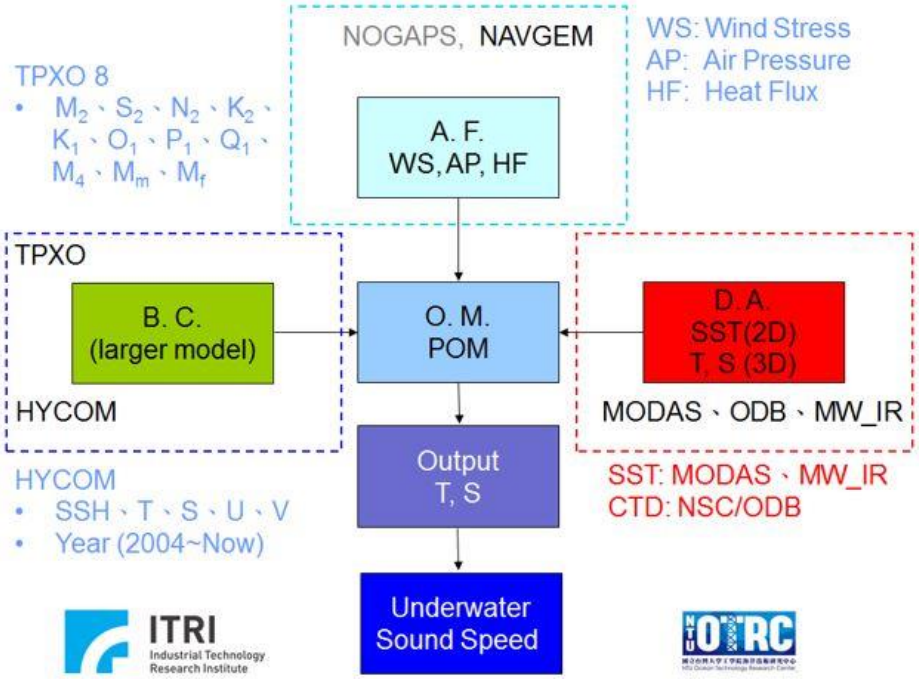
The humpback dolphin is listed as “Near Threatened” by the International Union for Conservation of Nature (IUCN).

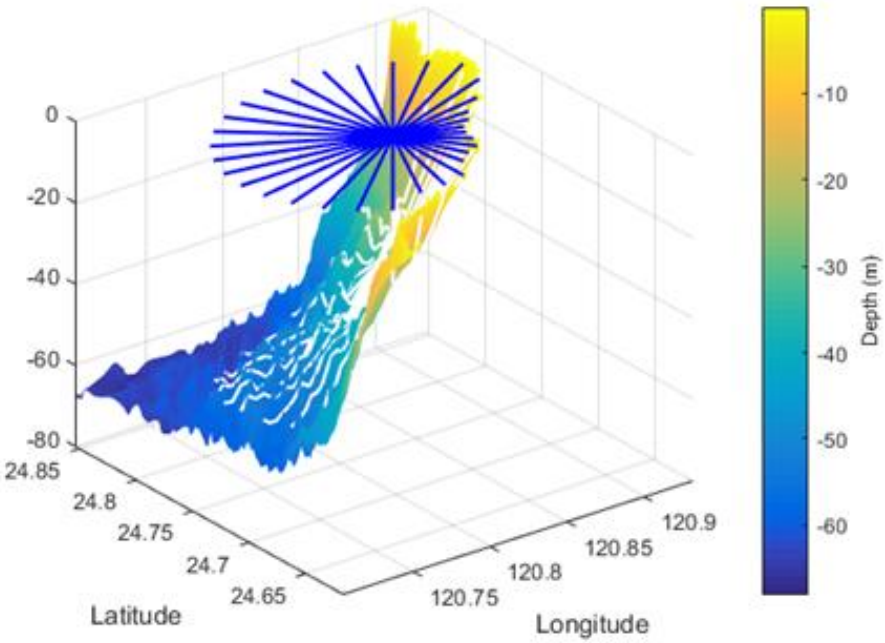
Underwater Noise Simulation





Environmental Data Base





Resolution: 1/24 degree (4.5 kilometer)
Time interval: 1 hour

海洋模式TCONFS

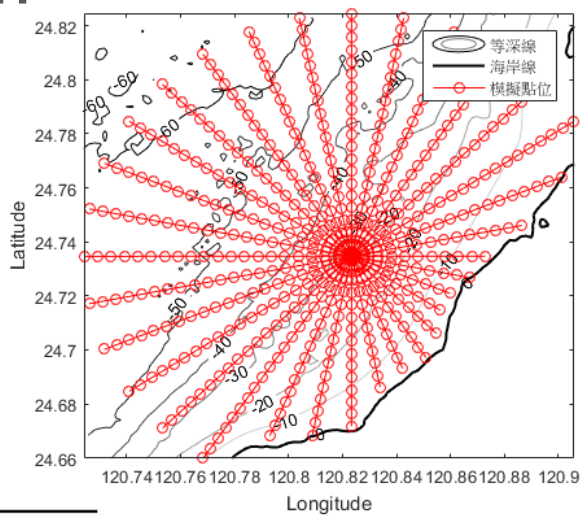
海域地形資料庫

National Taiwan University

Underwater Acoustics Laboratory
水下聲學實驗室

Ambient Noise Simulatin

水下背景噪音數值模式之使用者介面

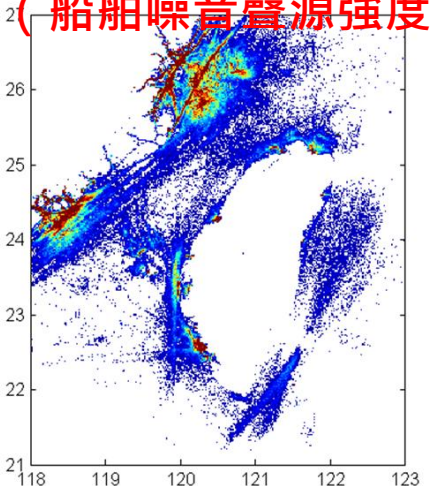


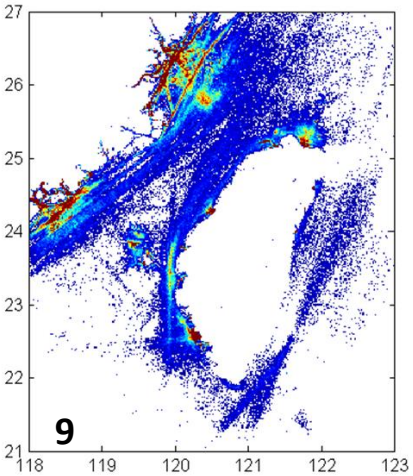
模式運算格點

Wind Speed (knot)	Frequency (Hz) 50	100	500	1k	25k
1	46.0	47.0	46.0	45.0	22.0
10	**49.0**	**50.0**	**49.0**	**48.0**	25.0
15	**55.4**	**57.2**	**56.2**	**56.2**	33.2
20	**61.5**	**62.7**	**61.7**	**61.7**	38.7
25	**64.0**	**66.1**	**63.7**	**63.7**	40.7
30	**68.1**	**69.0**	**66.5**	**65.0**	42.0
35	**70.9**	**70.0**	**68.6**	**67.1**	43.1
40	**72.0**	**71.5**	**69.5**	**68.0**	45.0
45	**72.5**	**72.7**	**70.2**	**68.7**	45.7
50	**75.0**	**73.5**	**70.9**	**69.4**	46.4

Unit: dB re 1μPa²/Hz/m² 風浪噪音聲源強度對照表

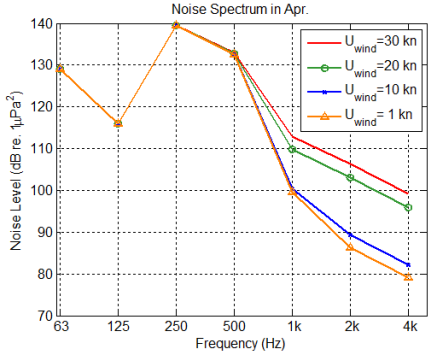
2014年4月與7月船舶密度
(船舶噪音聲源強度轉換



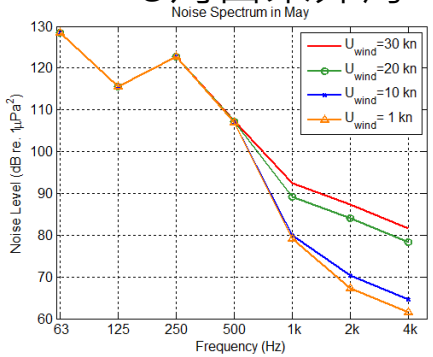


Simulation result

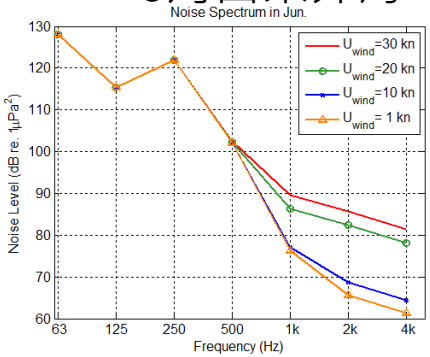
4月苗栗外海



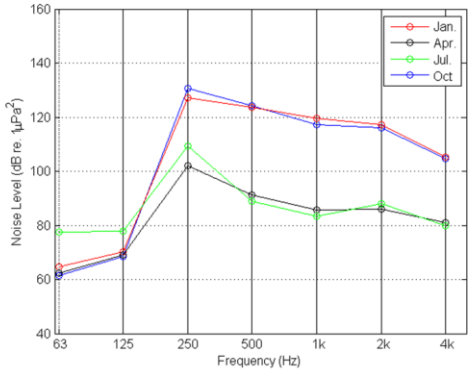
5月苗栗外海



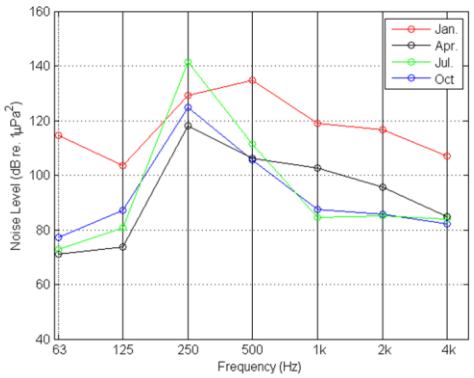
6月苗栗外海



104年苗栗外海



104年彰化外海



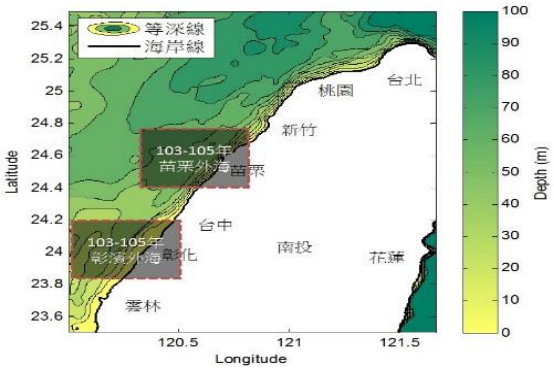
- **水下背景噪音數值模式已建立**
  - 透過地形、水文與底質資料庫估算音傳損耗
  - 透過航運密度與海面風速計算噪音源強度
  - 利用音傳損耗與噪音源強度進行水下背景噪音之模擬

Ambient Noise Measurement

National Taiwan University

Underwater Acoustics Laboratory 水下聲學實驗室

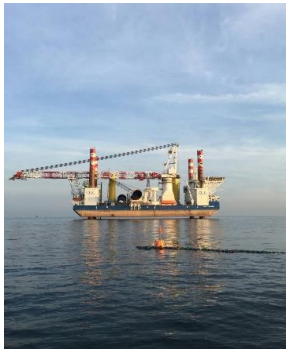
- 配合示範風場之推動時程，於民國103-105年針對臺灣西部海域進行水下背景噪音量測



計畫量測目標區域

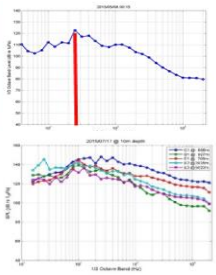
2014

- 完成苗栗N1及S1和彰化外海A1及A2離岸風場長期水下背景噪音量測



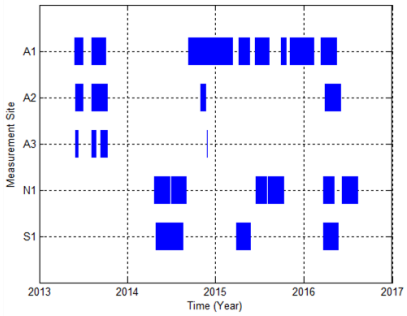
計畫區域施工噪音量測 **2015**

- 持續進行苗栗S1及彰化A1外海水下背景噪音量測
- 完成苗栗及彰化離岸風場海氣象觀測塔施工噪音量測

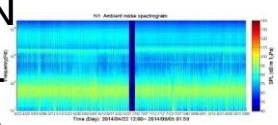


計畫區域水下噪音長期量測站**2016**

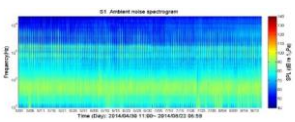
- 於2013至2016年完成時間長達1430天的背景噪音量測
- 完成風機打樁噪音量測



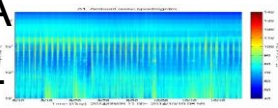
N1



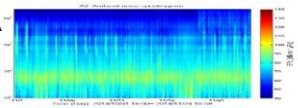
S1



A1

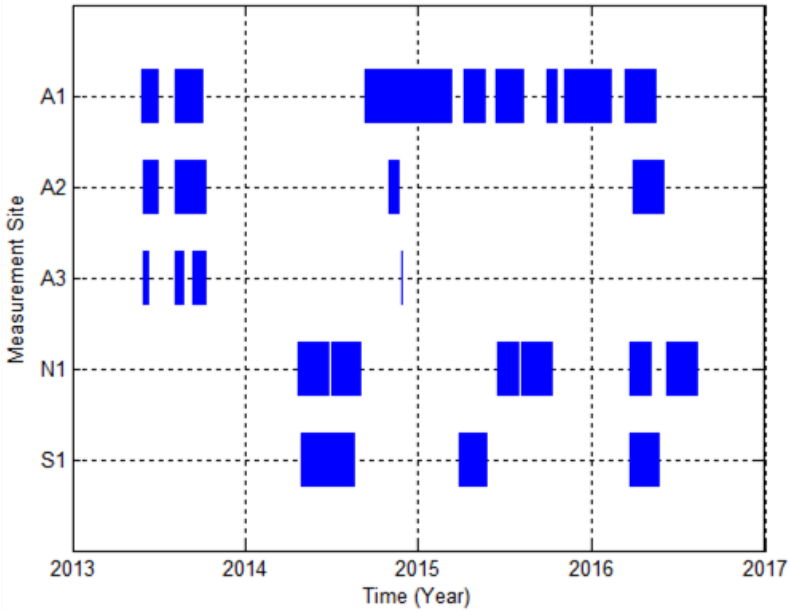


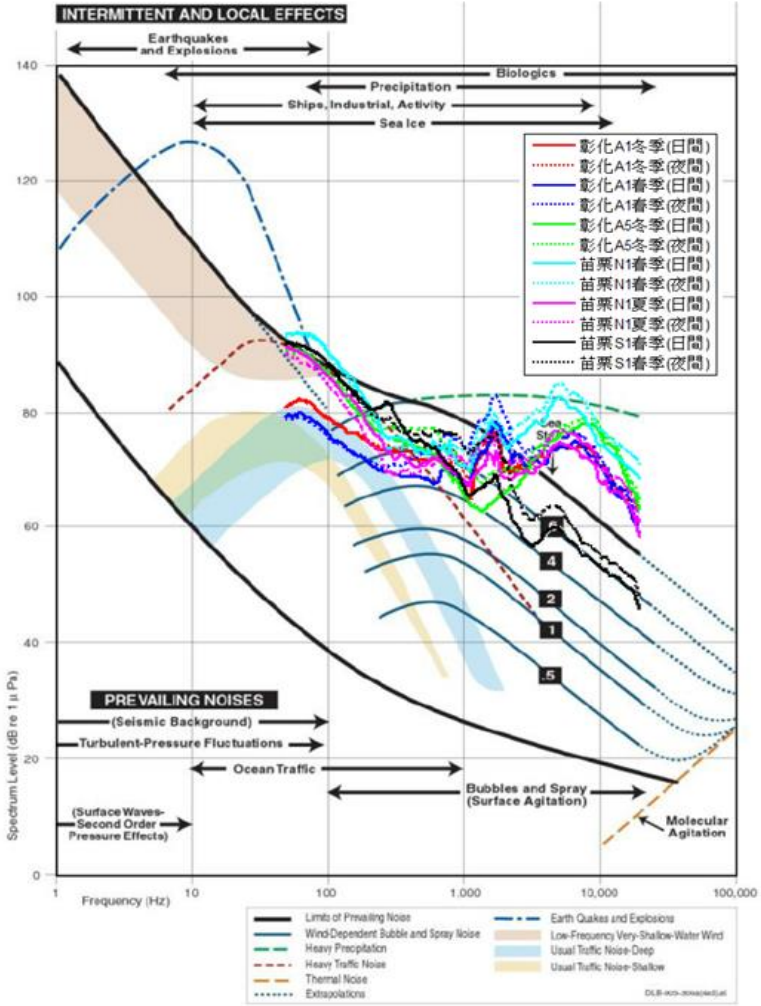
A2



2014- 2016 measurements

- (完成)苗栗外海N1, S1水下背景噪音量測
- (完成)彰化外海A1,A2, A3 水下背景噪音量測
- (完成)苗栗及彰化外海風海觀測塔施工噪音量
- 完成時間長達1430天的背景噪音量測
- 完成風機打樁噪音量測





III. Pile Driving Noise Measurement and Analysis

中華民國科技部
Ministry of Science and Technology, R.O.C.

經濟部能源局
Bureau of Energy, Ministry of Economic Affairs

MARINE MAMMAL COMMISSION

Noise Field Characterization in the Habitat of the East Taiwan Strait Indo-Pacific Humpback Dolphin during the Pile Driving Activity of Demonstration Offshore Wind Farm

Chi-Fang Chen[1]
Wei-Chun Hu [1], Jeff Chih-Hao Wu [1],
Nai-Chang Chen [1], Wei-Shien Hwang[1]
Shane Guan[2], Lien-Siang Chou[1]
Ruey-Chang Wei[3], Sheng-Fong Lin[4],
Derrick Lin [5]

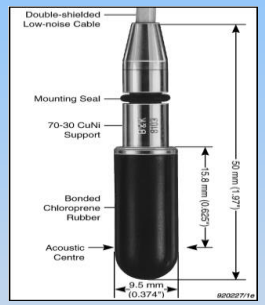
1. NTU 2. NOAA/NMFS 3. NSYSU 4. ITRI 5. Swancor R.E. Co.

III. PILE DRIVING NOISE MEASUREMENT AND ANALYSIS

- 2016.09 Noise measurement on Miaoli Demo site (performed by SWAncor Renewable Energy Co. Ltd.)
- Noise Measurement (Shipboard and Bottom-mounted)
- Instrumentation
- Duration: (#21) 9/3

II. PILE DRIVING NOISE MEASUREMENT : INSTRUMENTATION SETUP

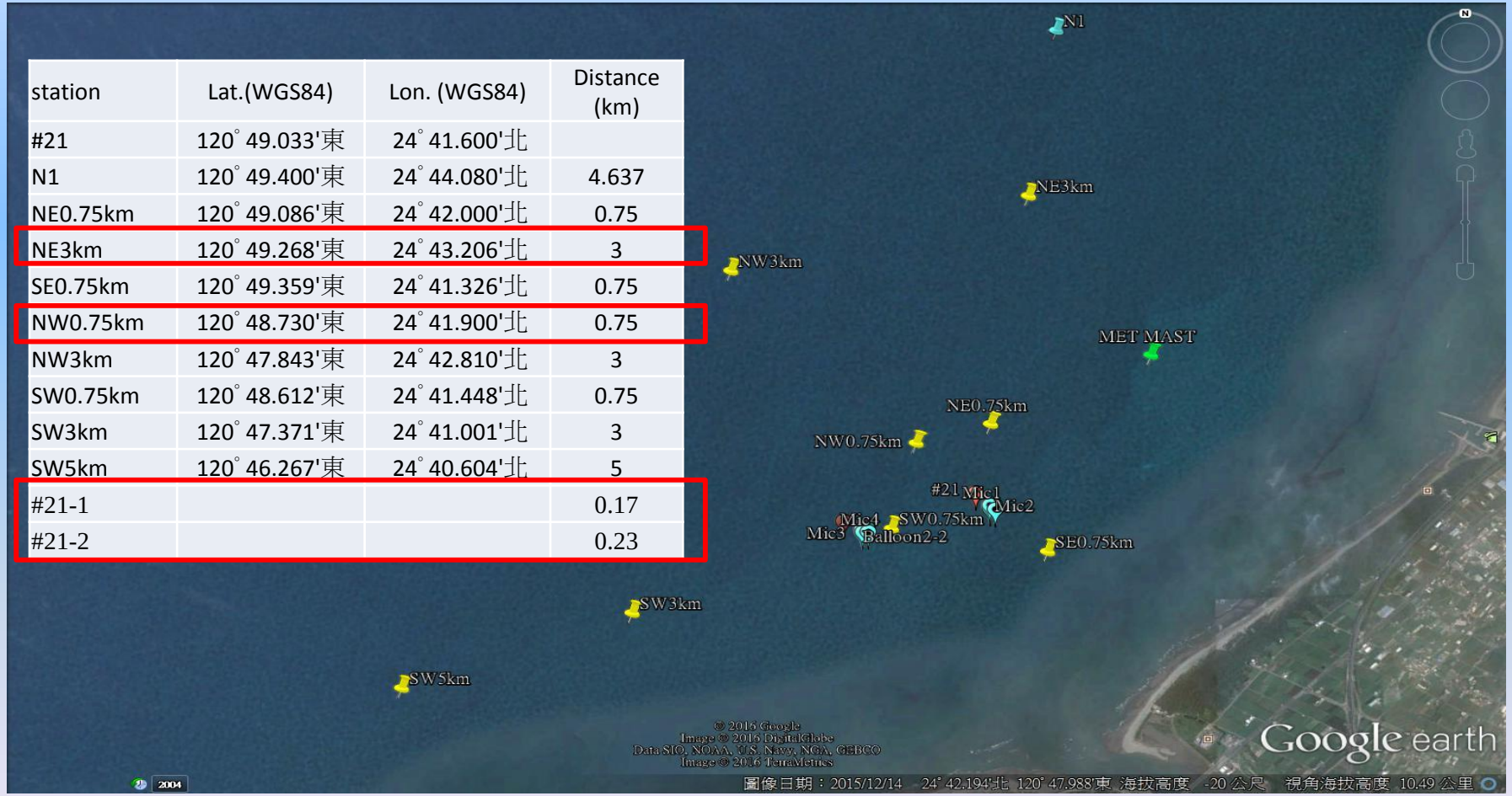
- Bottom-Mounted Measurement : SM3M
  - Standard Hydrophone (Sensitivity : -164 dB re 1V/μPa)
  - High-SPL Hydrophone (Sensitivity : -240 dB re 1V/μPa)
  - Dynamic range : 78 dB ~ 240 dB
  - 16 bits
  - Sampling rate: 48 kHz



- Shipboard Measurement: Brüel & Kjær Type 8103 Hydrophone
  - Hydrophone depth: 5m
  - Calibration on site with Brüel & Kjær Type 4228 calibrator:
  - Sensitivity : -215 dB re 1V/μPa
  - NI USB-4431 Data Acquisition System
  - Dynamic range: 100 dB
  - 24 bits
  - Sampling rate: 44.1 kHz

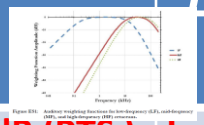
Measurement stations

station	Lat.(WGS84)	Lon. (WGS84)	Distance (km)
#21	120° 49.033'東	24° 41.600'北	
N1	120° 49.400'東	24° 44.080'北	4.637
NE0.75km	120° 49.086'東	24° 42.000'北	0.75
NE3km	120° 49.268'東	24° 43.206'北	3
SE0.75km	120° 49.359'東	24° 41.326'北	0.75
NW0.75km	120° 48.730'東	24° 41.900'北	0.75
NW3km	120° 47.843'東	24° 42.810'北	3
SW0.75km	120° 48.612'東	24° 41.448'北	0.75
SW3km	120° 47.371'東	24° 41.001'北	3
SW5km	120° 46.267'東	24° 40.604'北	5
#21-1			0.17
#21-2			0.23



#21 Pile Driving Noise(10Hz – 20 kHz) Data Summary

Noise Level / Range, m	(MF weighted 24-hour sound exposure level) $L_{E,MF,24h}$ dB re 1 μPa²s	(Unweighted Peak Pressure Level) $L_{flat,pk}$ dB re 1 μPa	(Unweighted Band Level) L_{rms} dB re 1 μPa,	Sound Exposure Level (Single Strike) SEL_{s-s} dB re 1 mPa²-s
NMFS criteria (MF)[1]	Level A: 185 dB (PTS)	Level A: 230 dB (PTS)	Level A: 180 dB	
US Navy (Finneran)[1]	(TTS) 179 dB	(TTS) 224 dB	Level B: 160 dB	*估算值 Estimate
230 m	197	200 - 204	183-187	176-180
750 m	178*	185 - 189*	173-177*	166
1,250 m	162*	180	169	162
1,500 m	160*	179*	166*	163*
3,000 m	157*	176	163	160



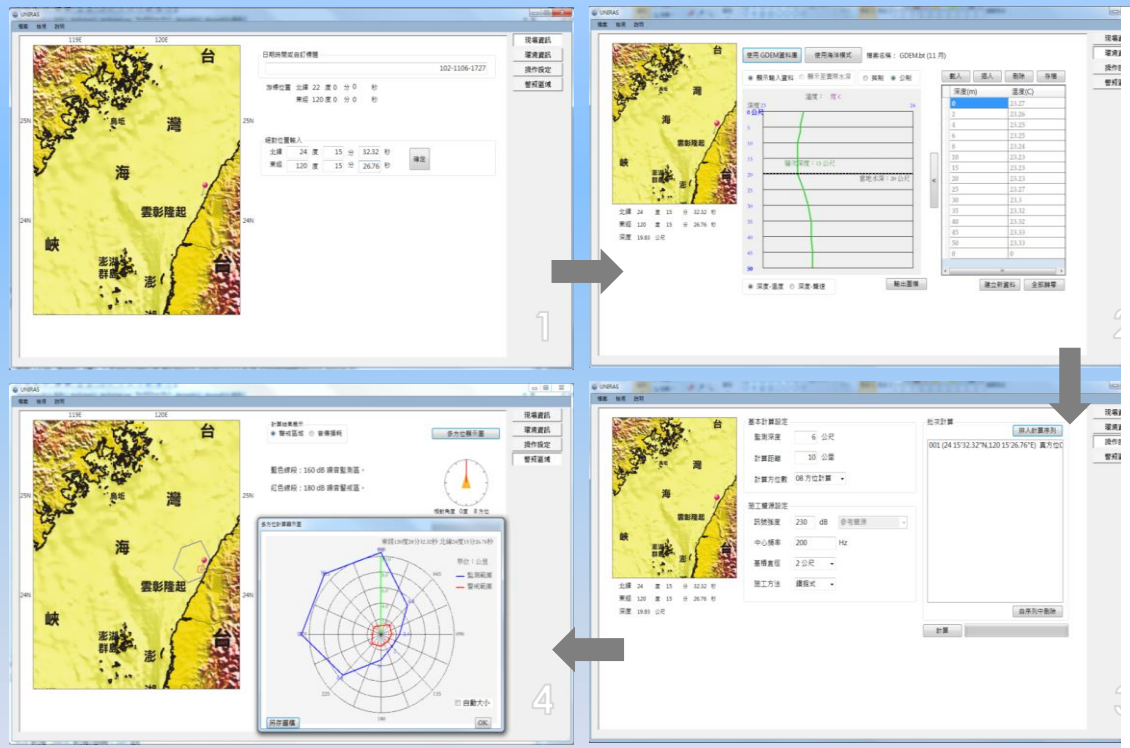
#21 Pile Driving) Noise Source Level Inversion

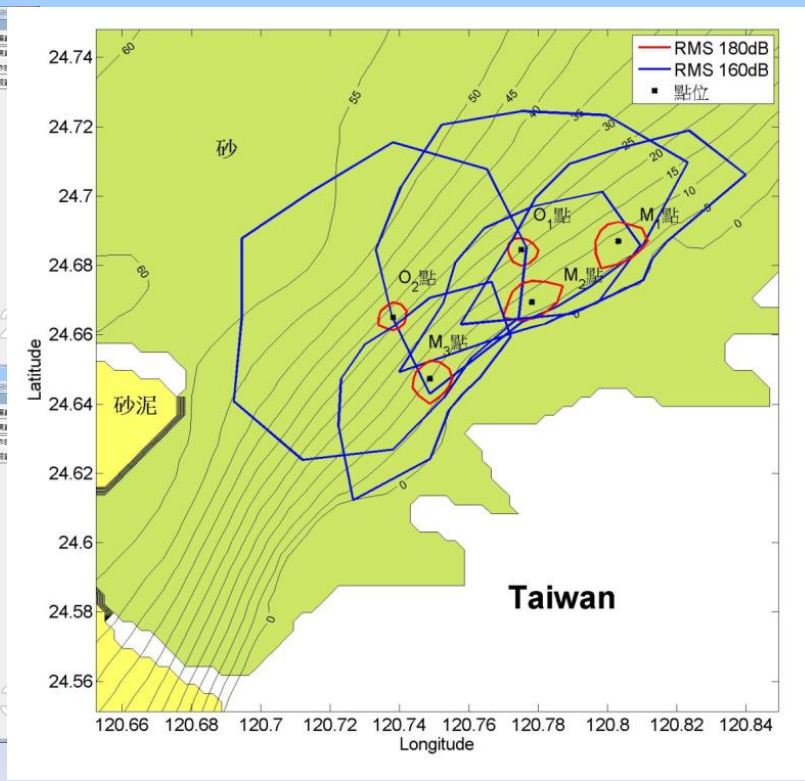
Noise Level / Range, m	(1) (Unweighted Band Level) L_{rms} dB re 1 μPa,	Sound Exposure Level (Single Strike) $SEL_{s\text{-}s}$ dB re 1 mPa^2-s	(2) TL, dB	(3) = (1)+(2) SL @1m, dB re 1 μPa	(4)=(3)-20 SPL @10m
230 m	183-187	176-180	38	221	201
750 m	173	166	43	216	196
1,250 m	169	162	43	212	192
1,500 m	166*	163*			
3,000 m	163	160	55	218	198

Underwater Noise Impact Range Alert System

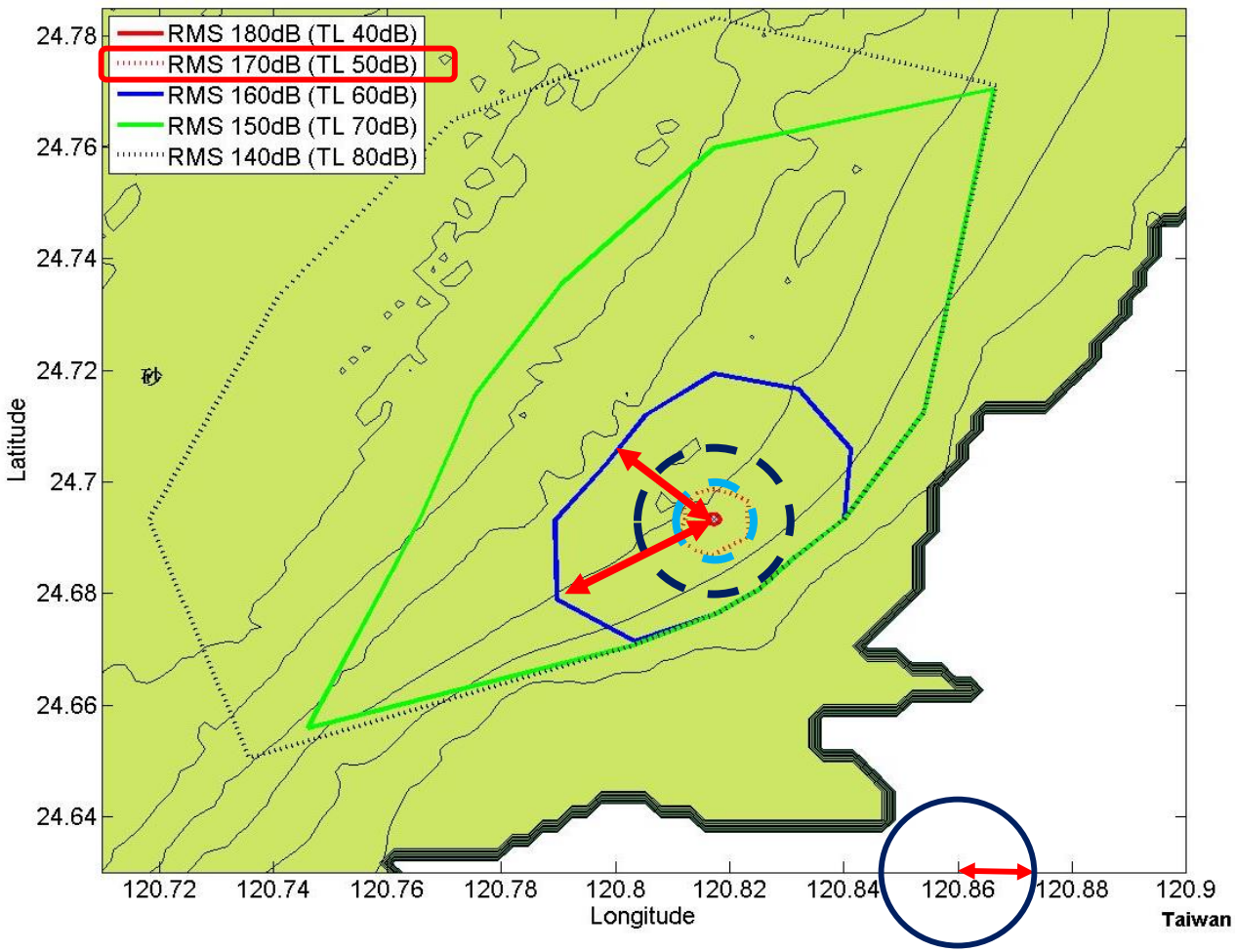
UNIRAS

ITRI&NTU
2013





Simulation of Noise Field @#21 pile



O : radius 1500m

O :radisu750m

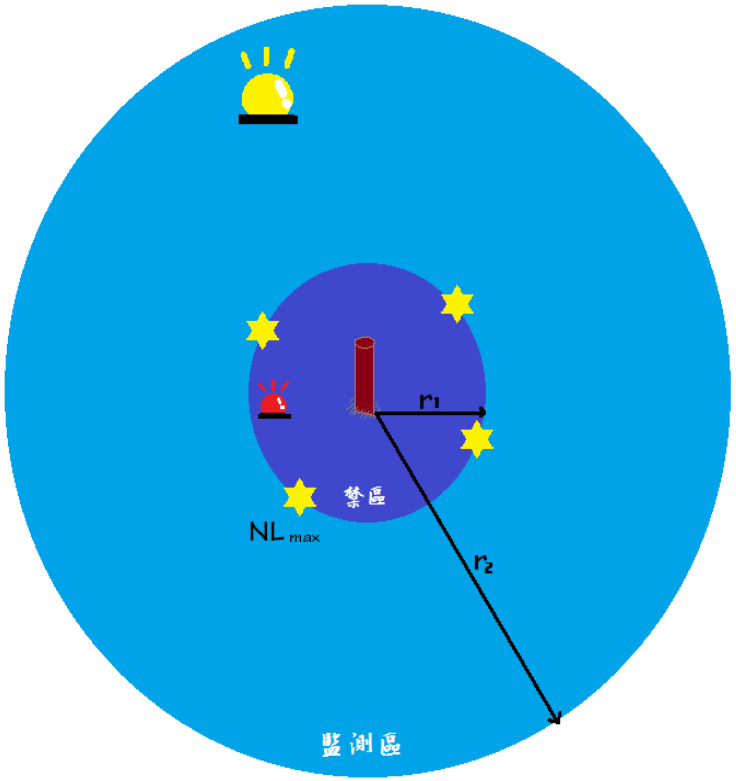
2km

PILE DRIVING MONITORING

Noise gauge, PAM

EXCLUSION ZONE

MONITORING ZONE



NL_{max} = NL 最大噪音量容忍值

NL @ $r_1 < NL_{max}$

$L_{E,MF,24h}$ <179 dB re 1 μPa²s

$L_{pk,flat}$ <190-220dB re 1uPa

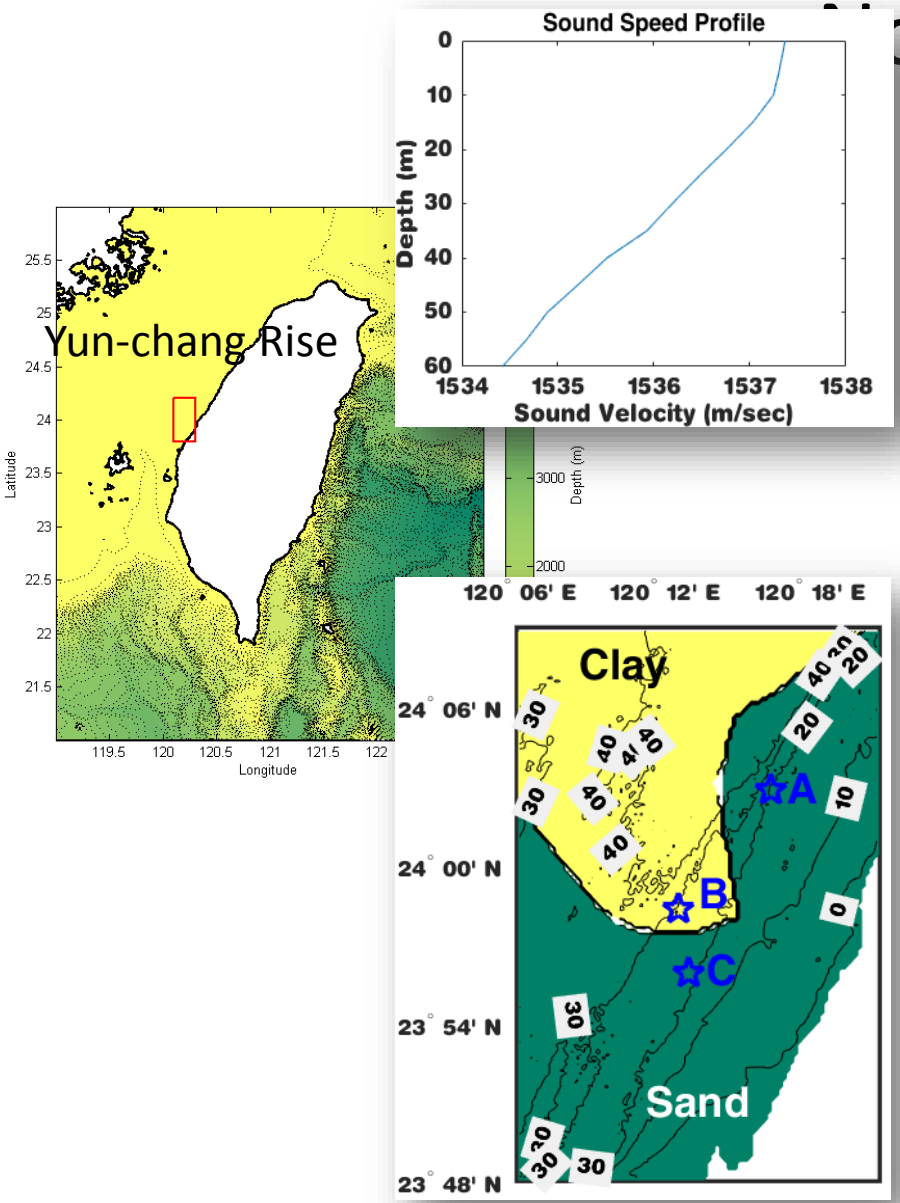
L_{rms} <180 dB re 1uPa

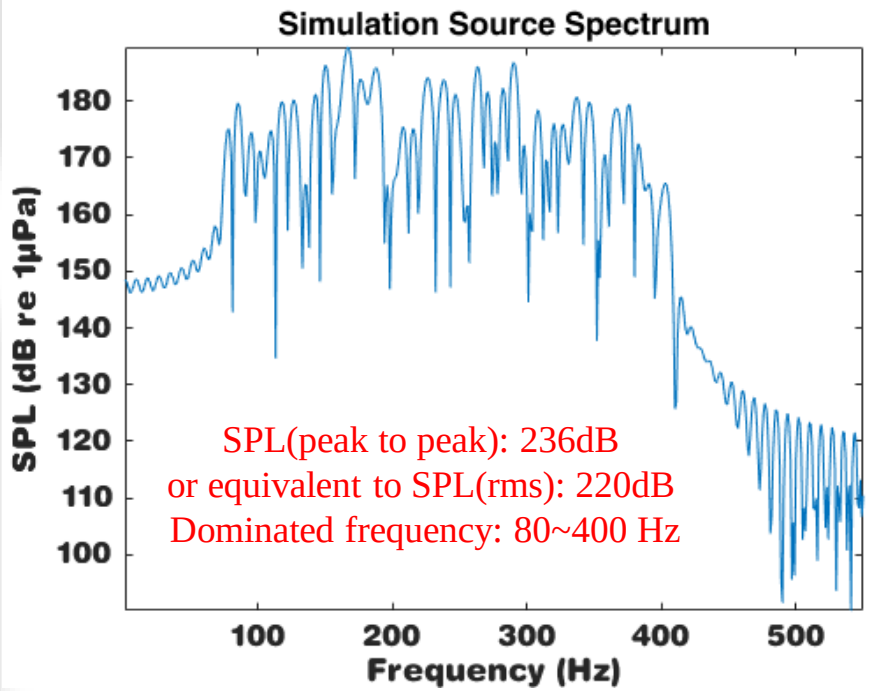
r_1 = 750m

r_2 = 1500 m

參考:胡惟鈞、陳琪芳、周蓮香、吳誌豪、Shane Guan 、魏瑞昌、陳乃菖、王煒傑、李沛沂、楊瑋誠,“離岸風力發電水下打樁噪音對中華白海豚棲地的影響”，2016台灣風能協會會員大會暨學術研討會

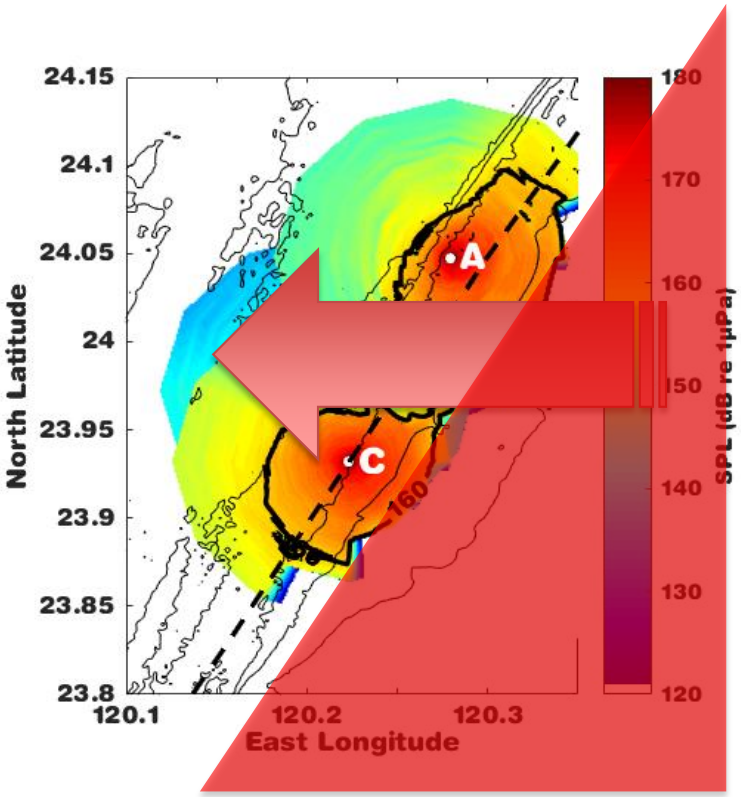
Simulation for Pile Driving Noise





Fourier Synthesis for Broadband Simulation

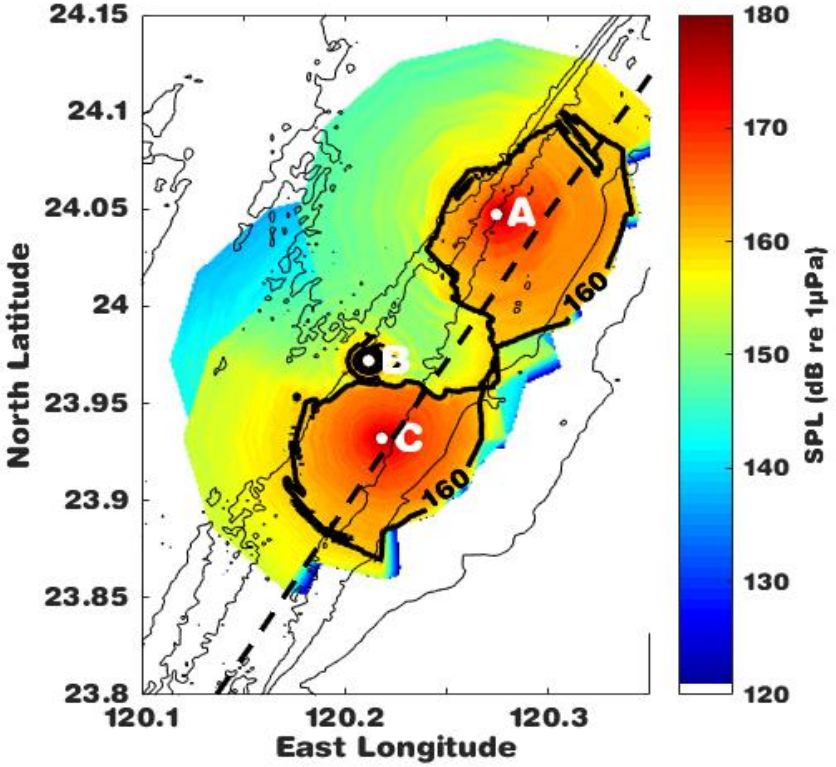
Results of Simulation for Pile Driving Noise



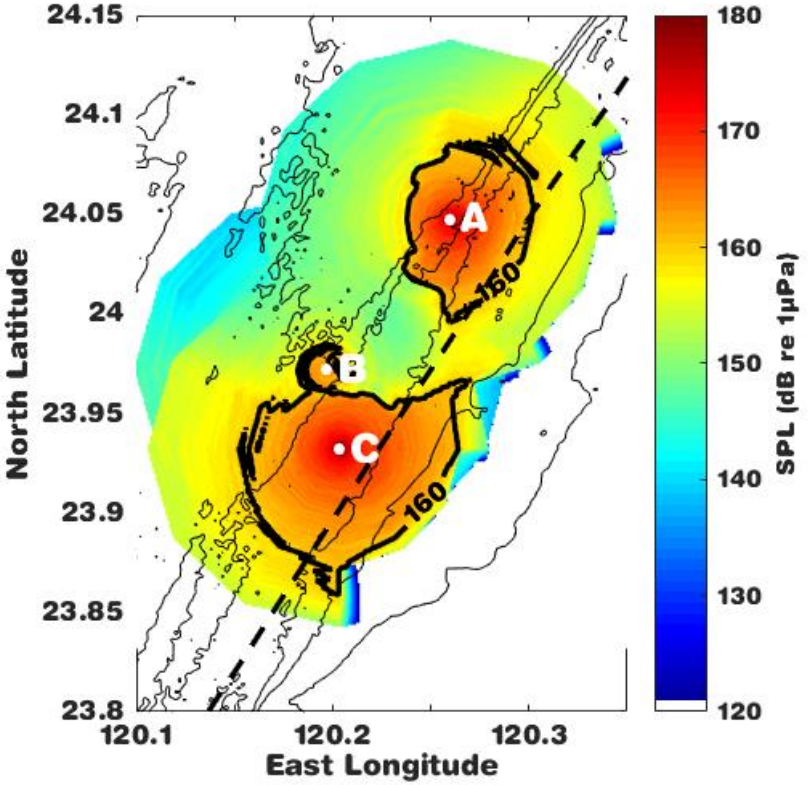
- Level B Harassment
  - Impulsive sound sources
  - 160 dB (rms) re 1 μPa
- Chinese White Dolphin conservation area
- Reduce the impact
  - Move points A, B, and C to the west
  - 750 m and 2 km
  - Developers lost 1 to 4 rows of wind turbines.

Results of Simulation for Pile Driving Noise

750 m

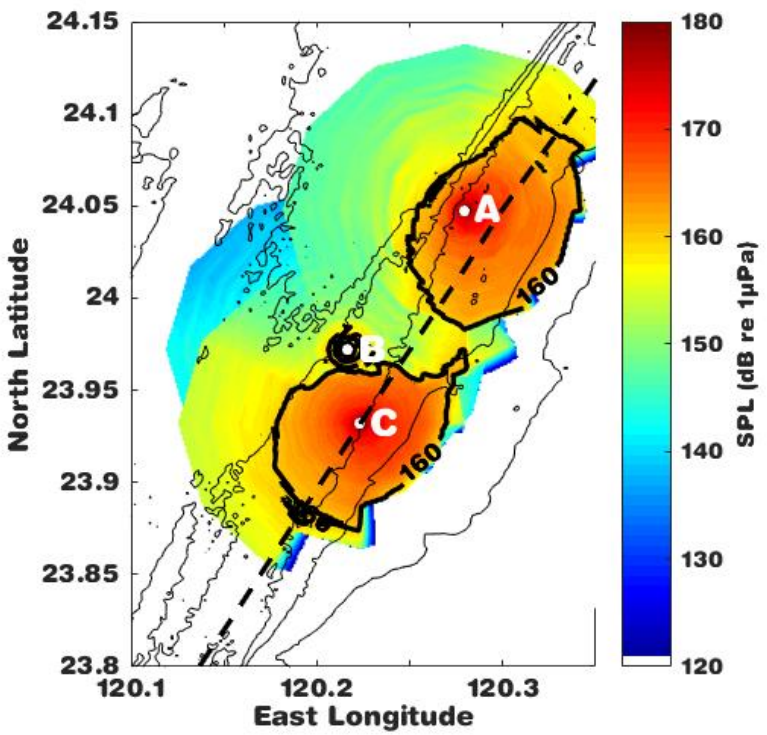


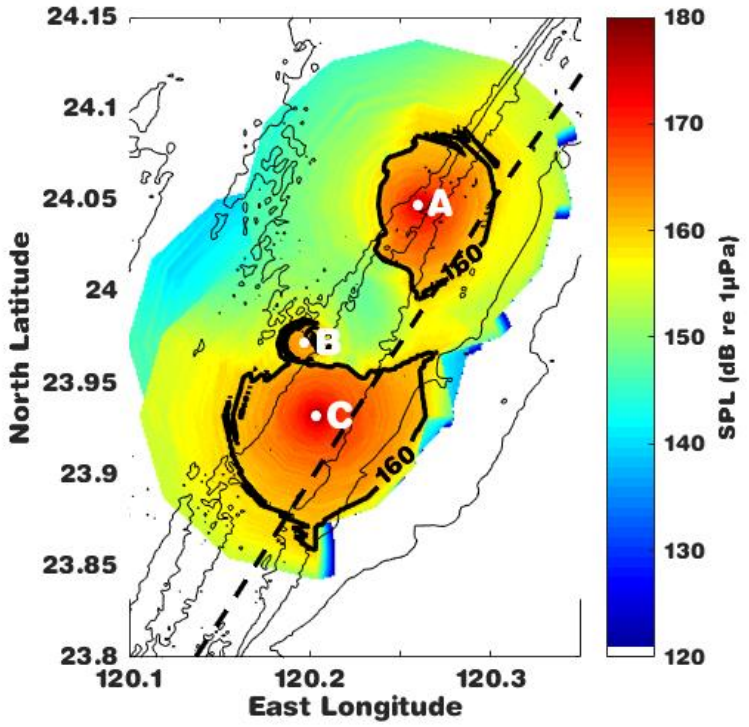
2 km



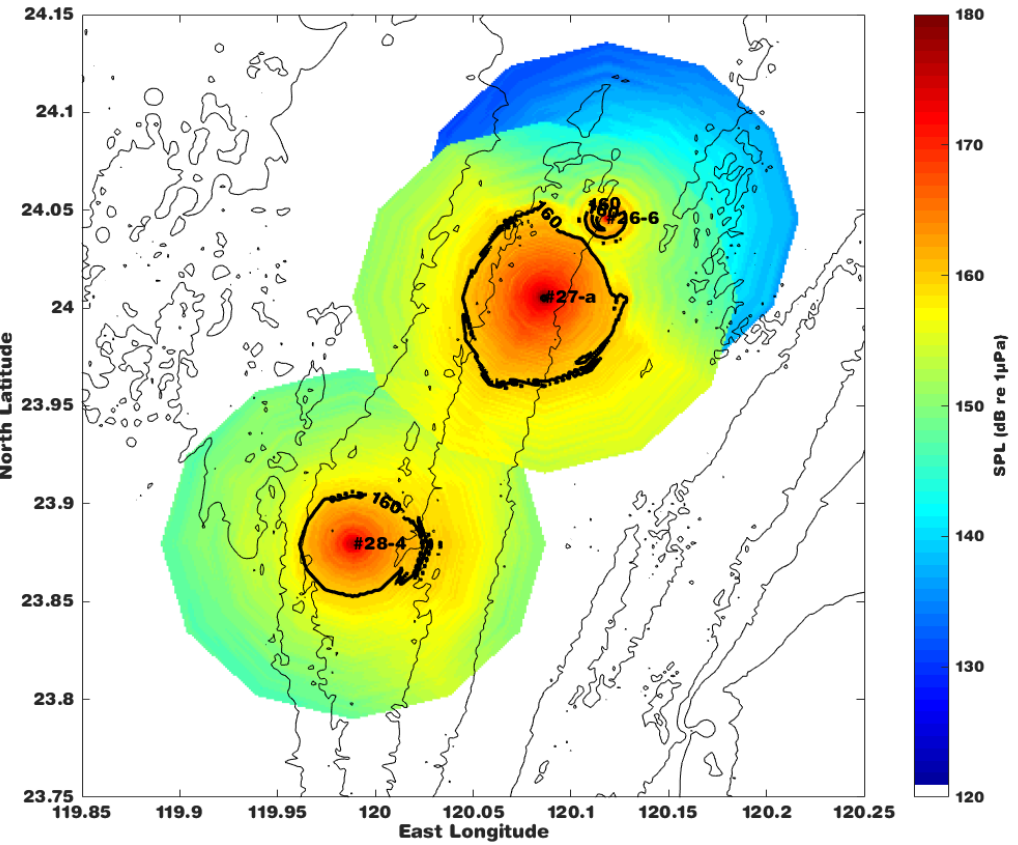
Summary of Simulation for Pile Driving Noise

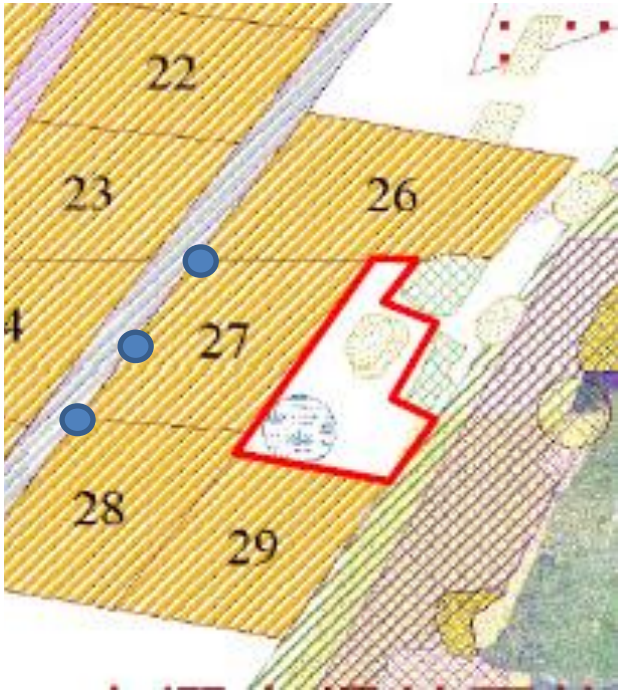
- The impact zone of point A is significantly reduced when it move to the deeper water in the west.
- The pile driving noise of point B is quickly decreased because of the clay bottom.
- Noise mitigation is needed at point C.





CASE II Three piles drive at the same time



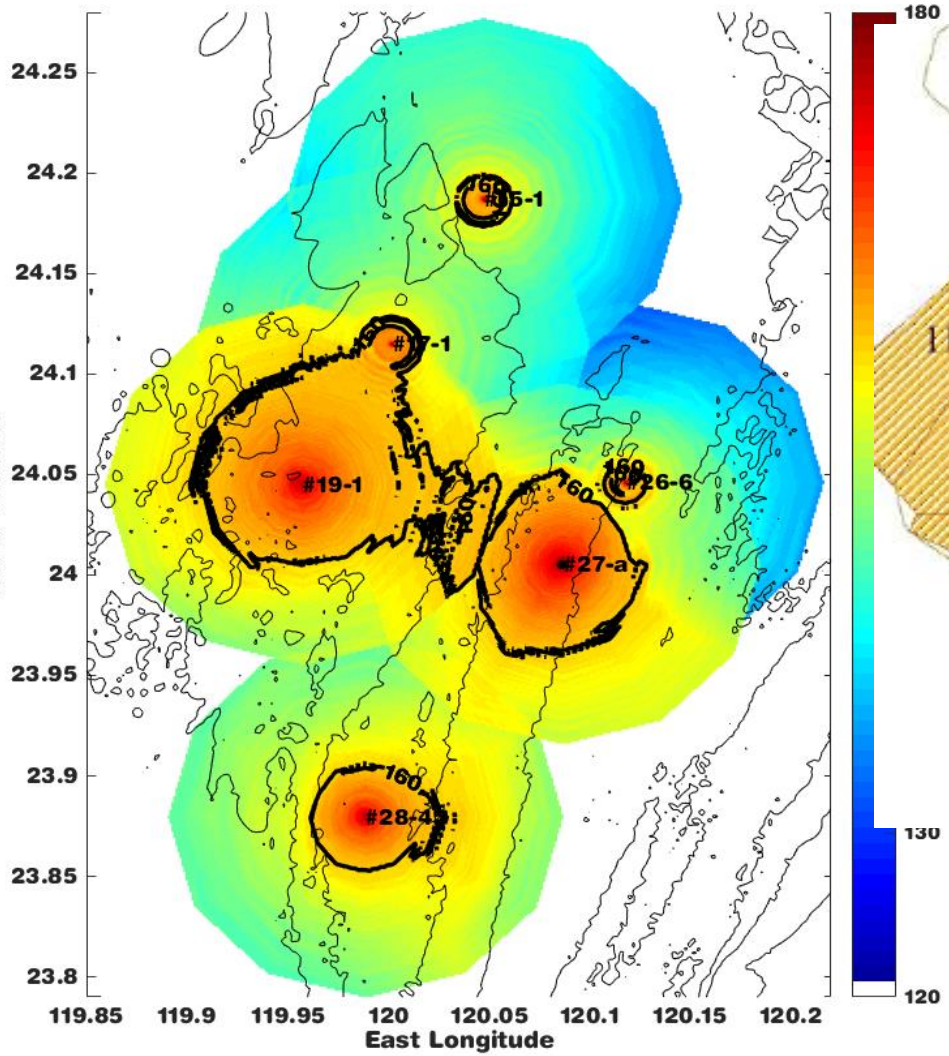


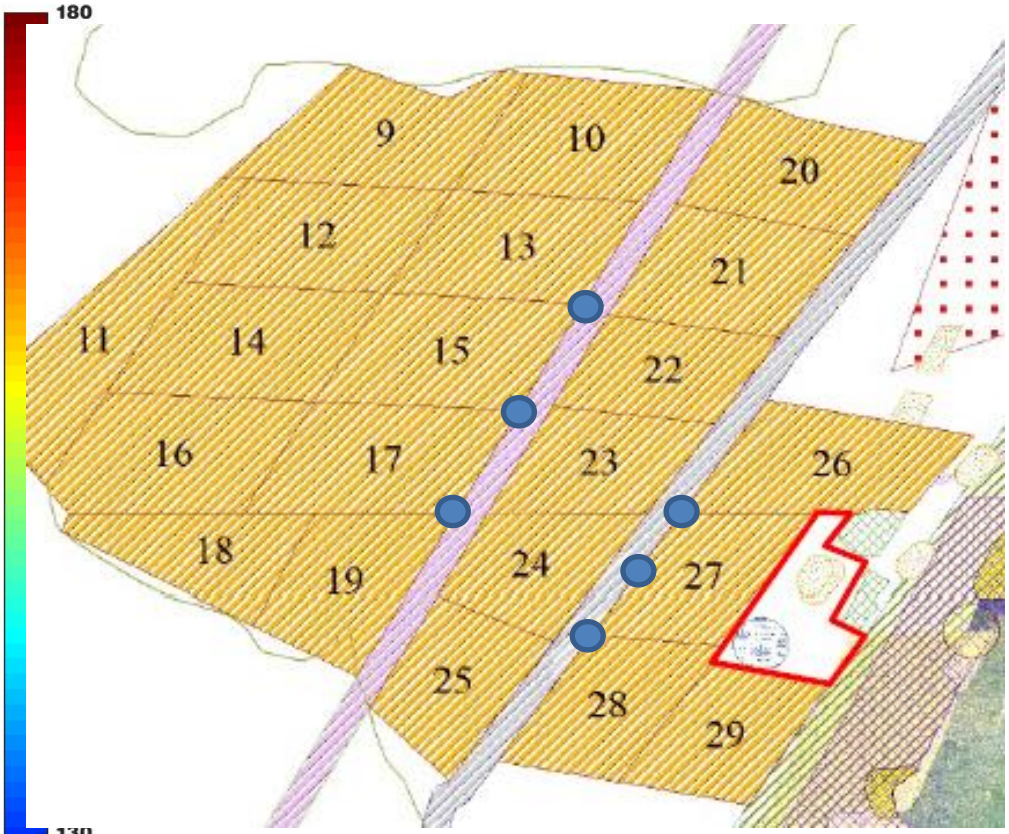
National Taiwan University

CASEIII

Six piles drive at the same time

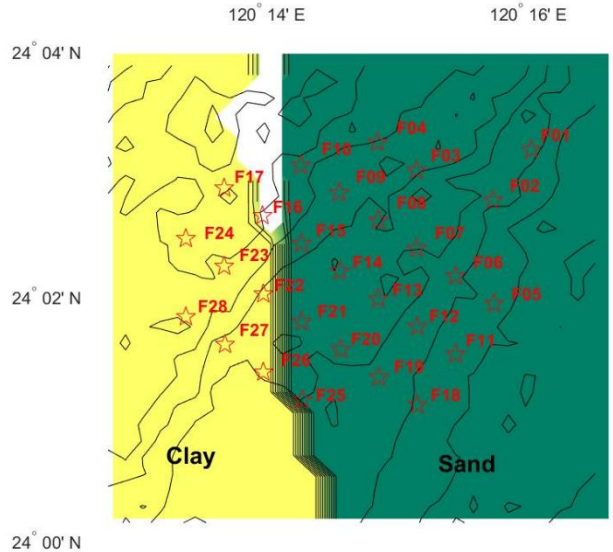
Underwater Acoustics Laboratory
水下聲學實驗室

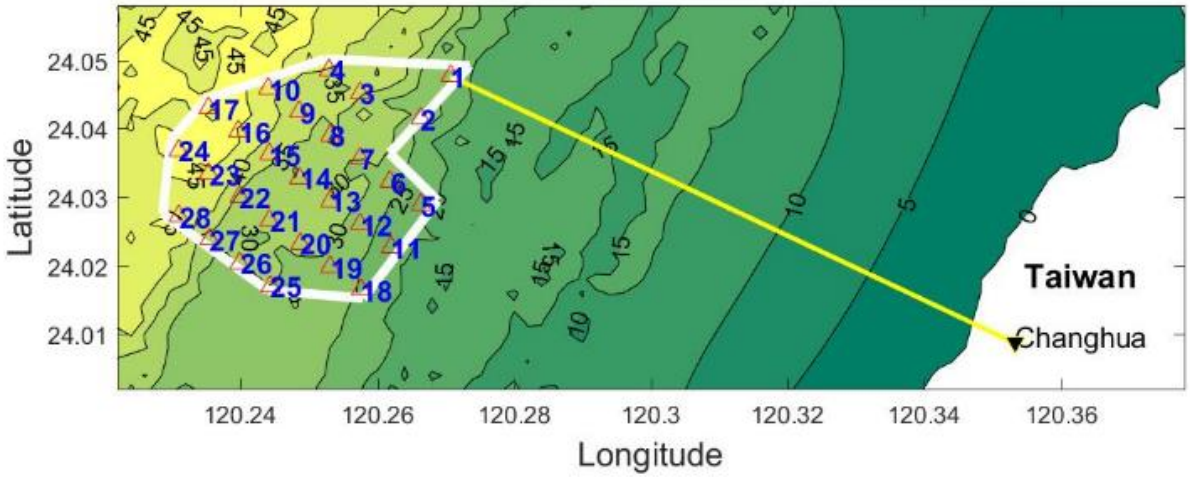




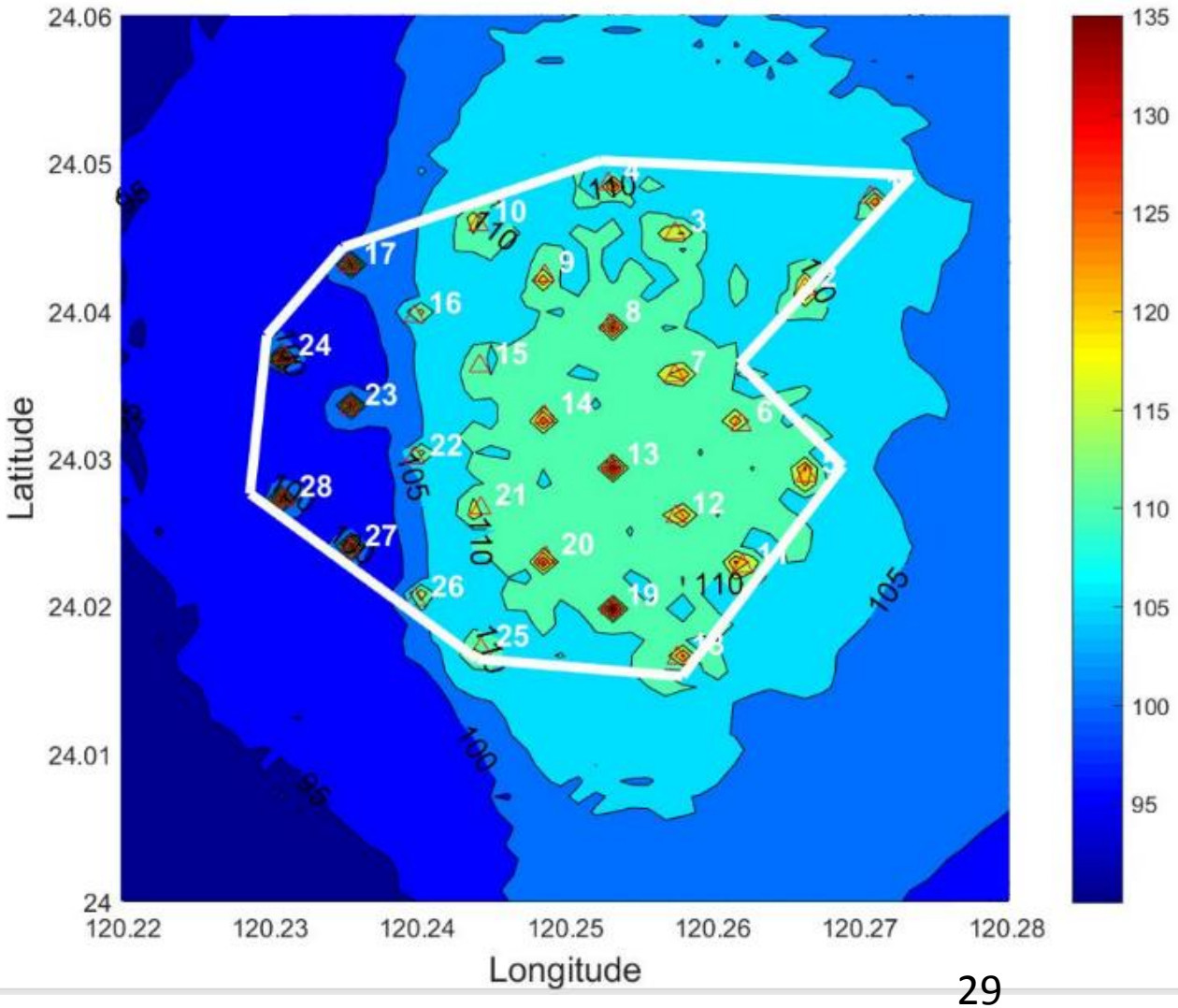
Simulation for Operation Noise

- Operational noise
  - 144 dB re 1μPa @ 1m, 125 Hz
  - Single frequency simulation
- Level B Harassment
  - Continuous sound sources
  - 120 dB (rms) re 1 μPa





Results of Simulation for Operation Noise



National Taiwan University

Underwater Acoustics Laboratory
水下聲學實驗室

Thank You For Your Attention

Provided by Prof. Lien-Siang Chou